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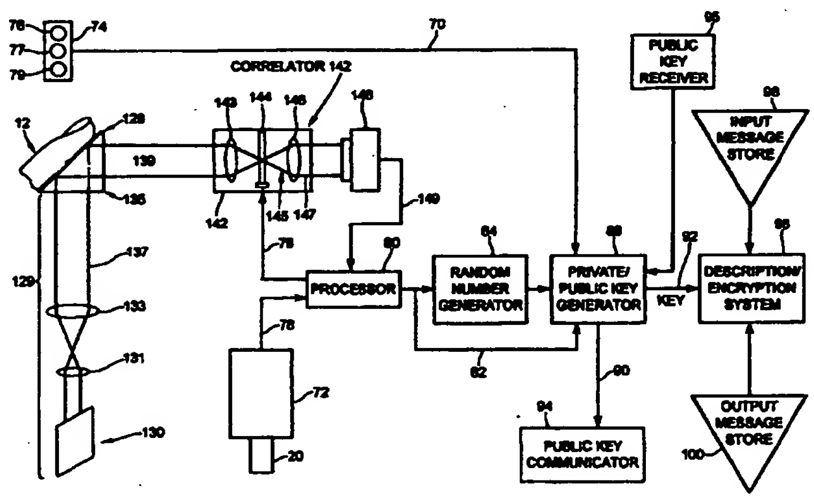

(57) Abstract

A key generation system is implemented as follows. In an enrolment apparatus, a unique number for use with PIN operated machines or public key cryptography system is generated by manipulation of fingerprint information of a subscriber. A filter is then generated which is a function both of the Fourier transform of the subscriber's fingerprint(s) and of the unique number. This filter is stored on a subscriber card. When the subscriber wishes to generate his key, he inputs his card to a card reader of an apparatus and places his finger(s) on a fingerprint input. The apparatus generates an optical Fourier transform from the fingerprint input. The Fourier transform signal is incident on to a spatial light modulator programmed with the filter information from the card. An inverse transform is generated from the filtered signal and this is used to regenerate the key that will be used as the PIN in a PIN operated device, or as the private key in a public key cryptography system.

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BIOMETRIC CONTROLLED KEY GENERATION

Background of the Invention

1. Field of the Invention

This invention relates to a system for generating a key under the control of a biometric, such as a fingerprint. The system has application in a public key cryptographic system and for devices requiring a personal identification number (PIN) for operation.

2. Description of the Related Art

In a public key cryptosystem, a plain text message may be encrypted by inputting the message and an enciphering key to an encryption algorithm. To decipher the message, the encrypted message is input to the inverse of the same algorithm along with a deciphering key. As with many encryption techniques, the encryption algorithm effects transformations of the plain text message which are so complicated it is computationally infeasible to reverse the process even if the algorithm is known. A peculiarity of public key systems is that it is also computationally infeasible to determine the deciphering key from the enciphering key. Consequently, in a public key cryptosystem, both the algorithm and the enciphering key may be made available to the public without jeopardising the security of a message enciphered with the enciphering key. Hence the term "public key" for the enciphering key. The deciphering key, which is confidential, is known as a "private key". With a public key system, anyone who wishes to receive encrypted messages may make an encryption algorithm and a public key freely available. Moreover, some public key systems allow the transmission of a "digital signature" that prevents forgery of messages by a receiver as well as a third party.

By way of example, with the known "knapsack" cryptosystem, a public key is derived from a private key utilising modular arithmetic. Each element in the array (vector) forming a private key is multiplied by a large prime number, x, and divided by a second large prime number, y. The corresponding element of the public key vector is the

remainder from this operation. In order to encrypt a plain text message, the message is digitised and the digital string grouped into arrays (vectors) each having the same number of elements as the number of elements in the array which comprises the public key. The encrypted message is formed from the vector dot product of the public key vector with each vector formed from the digitised plain text message.

Clearly the exemplary encryption technique and the technique for deriving a public key from a private key make it computationally infeasible to determine either the private key or the plain text message even though the algorithm, along with the encrypted text, is known. There are, however, known techniques for structuring a private key vector such that, with it, the plain text can be rapidly derived from an encrypted message. Two sample techniques in this regard are described in an article entitled "The Mathematics of Public-Key Cryptography" Scientific American August 1979, pages 146 to 157.

The problem with such public key cryptograph systems is that, in use, they require a secure, yet readily available, private key. The private key has to either be remembered, which is not practical, or stored in a secure place and retrieved. The security of storage therefore is at best dependent on password access which itself can be compromised.

A number of devices, such as automated teller machines (ATMs) and symmetric encryption/decryption systems, require the entry of a PIN for operation. A PIN therefore acts as a private key which permits operation of such devices. Devices requiring a data key for operation share the same problem as identified for public key cryptographic systems: the data key must be secure and yet readily available. To mitigate this problem, PIN operated devices often utilize a short key which may be memorized by the user. However, not all users do memorize their PIN and, in any event, use of a short PIN reduces the security of the PIN operated device.

This invention seeks to overcome drawbacks of the known prior art and provide an extremely secure private key which is not even known by the user yet is readily accessible.

Summary of the Invention

According to the present invention, there is provided a biometric controlled key generation system, comprising: a body part input for generating an optical information signal impressed with a biometric; Fourier transform means along a path of said optical information signal to obtain a Fourier transform representation of said information signal; a programmable filter responsive to said Fourier transform means for filtering said Fourier transform representation of said information signal to obtain a filtered Fourier transform representation; means for reading data from a data carrier storing filter information and for programming said programmable filter with said filter information data; inverse transform means responsive to said filter to inverse Fourier transform said filtered Fourier transform representation to obtain an inverse transform representation; key generating means responsive to said inverse transform means for generating a private key.

According to another aspect of this invention, there is provided a method for generating a private key, comprising the steps of: generating an optical information signal impressed with a biometric; obtaining a Fourier transform representation of said information signal; receiving a filter and filtering said Fourier transform representation of said information signal with said filter to obtain a filtered Fourier transform representation; obtaining an inverse Fourier transform representation of said filtered Fourier transform representation; generating a private key from said inverse transform representation.

Brief Description of the Drawings

In the figures which disclose example embodiments of the invention,
figure 1 is a schematic diagram of an enrolment apparatus made in accordance with this invention,
figure 2 is a schematic diagram of an encrypting/decrypting apparatus made in accordance with this invention,
figure 3 is a schematic diagram of a portion of figure 2, and
figure 4 is a schematic diagram of a PIN generating apparatus made in accordance with this invention.

Description of the Preferred Embodiments

In the following, lower case letters represent functions in the "spatial

domain" and upper case letters represent the "Fourier transformed frequency domain". Also, we use the following terminology: "Fourier transform" denotes a transformation from the spatial domain to the frequency domain, and "inverse Fourier transform" denotes a transformation from the frequency domain to the spatial domain. It should be noted that when the inverse Fourier transform is implemented optically (using a lens), the transformation is in fact equivalent to the Fourier transform. The consequence of this is that a coordinate reversal occurs in the resulting spatial domain. On the other hand, digital implementation of the inverse Fourier transform can be accomplished as mathematically defined, and so no such coordinate reversal occurs. However, both (optical and digital) implementations of the inverse Fourier transform can be used to produce the correlation operation which is required for this invention.

An individual who wishes to use the encrypting and decrypting apparatus of this invention is enroled by way of enrolment apparatus 10 of figure 1. With reference to figure 1, enrolment apparatus 10 comprises an input system 29 with a light source 30, which may be a coherent source, an expander lens 31, and a collimator lens 33 to illuminate a prism 35 with a beam 37. One face of the prism forms an input screen 28. The individual to be enroled places a finger (or fingers) 12 on the input screen. The input system utilizes the principle of total internal reflection to read the pattern formed by the furrows of the input fingerprint pattern. That is, a furrow will create an air space over the surface of a glass screen, allowing light which is internally reflected from the interior surface of the screen to proceed unimpeded. Ridges, however, will be in contact with the surface, where they will scatter and absorb a portion of the illuminating light. This effect is known as frustrated total internal reflection. In the result, the output beam 39 from the prism is an information beam carrying the fingerprint pattern, p. The optical beam 39 inputs a lens 40 which images the fingerprint information onto an Image Capture and Digitizer Device ICDD, 41, comprising a light detector array, an A/D converter and a processor. The ICDD converts the optical fingerprint information beam into a two-dimensional grey scale digital representation. The digital output 42 of the ICDD is input to a unique filter generator 43 and to a unique number generator 44.

The unique number generator 44 generates an array of numbers. This may be accomplished in any of a number of ways. For example, a Fourier transform of the

fingerprint information may be calculated to obtain the Fourier transform co-efficients of the transform. Selected ones of these Fourier transform co-efficients may then be chosen and combined to generate a number u. It will be apparent that this number u is unique to the particular fingerprint(s) placed on the input screen. Alternatively, u can be generated by a random number generator seeded with the selected Fourier transform co-efficients. The unique number u is then used to generate an array of numbers $g = \{g_1,.....g_n\}$ such that the values in the elements of g represent the unique number u. For example, if u is a k-digit base 10 number and if in any subsequent measurement of the values $g_1.....g_n$, the detecting instrument will have a known error in detection which only allows β distinct values from 0 to m - 1 inclusive (m is the dynamic range of the detector), n would be chosen to be the integer greater than or equal to $\log_\beta 10^k$. The unique number u can then be expanded into elements of g by using modulo division, i.e.:

$$g_1 = \text{Integer of } \frac{u}{\beta^{n-1}}$$

$$g_2 = \text{Integer of } \frac{u \bmod \beta^{n-1}}{\beta^{n-2}}$$

$$g_3 = \text{Integer of } \frac{(u \bmod \beta^{n-1}) \bmod \beta^{n-2}}{\beta^{n-3}} = \text{Integer of } \frac{u \bmod \beta^{n-2}}{\beta^{n-3}}$$

etc. The array, g, is input to the unique filter generator 43.

The unique filter generator 43 calculates the digital Fourier transform, P, of the fingerprint information and generates a two dimensional filter function, F, as follows. The mathematical multiplication of the fingerprint transform, P, with the filter, F, produces the two-dimensional light distribution S. F is generated so that the inverse Fourier transform of S, denoted by s, is equal to a series of n displaced delta-like functions δ_1, $\delta_2,.....\delta_n$, where the square of the amplitude of δ_i is equal to the corresponding value g_i in the array g. This may be represented mathematically by the following sets of equations which for convenience will be described in one dimension:

Let $p(x)$ be the input fingerprint pattern signal

$P(u)$ be the complex Fourier transform of the signal, denoted by $|P(u)| \exp(j\phi(u))$, where $\phi(u)$ is the phase of the Fourier transform

$F(u)$ be the filter function

and $s(x)$ be the output signal

We desire $s(x)$ to have the following form;

$$s(x) = \sqrt{g_1}.\delta(x-x_1) + \sqrt{g_2}.\delta(x-x_2) + \ldots \sqrt{g_n}.\delta(x-x_n)$$

that is n delta functions at positions $x_1, x_2, \ldots x_n$ and relative intensities $g_1, g_2, \ldots g_n$ respectively

Then,

$$S(u) = \int \sqrt{g_1}.\delta(x-x_1).\exp(-j2\pi ux)dx + \int \sqrt{g_2}.\delta(x-x_2).\exp(-j2\pi ux)dx + \ldots$$

Let $x' = x-x_1$, $x'' = x-x_2$, etc.

$$S(u) = \int \sqrt{g_1}.\delta(x').\exp(-j2\pi u(x'+x_1))dx' + \int \sqrt{g_2}.\delta(x'').\exp(-j2\pi u(x''+x_2))dx'' + \ldots$$

$$= \sqrt{g_1}.\exp(-j2\pi ux_1). \int \delta(x').\exp(-j2\pi ux')dx' + \sqrt{g_2}.\exp(-j2\pi ux_2). \int \delta(x'').\exp(-j2\pi ux'')dx'' + \ldots$$

$$= \sqrt{g_1}.\exp(-j2\pi ux_1) + \sqrt{g_2}.\exp(-j2\pi ux_2) + \ldots$$

We require that

$$P(u).F(u) = S(u)$$

Thus, $F(u) = \dfrac{S(u)}{P(u)}$

That is,

$$F(u) = \frac{\sqrt{g_1}.\exp(-j2\pi ux_1) + \sqrt{g_2}.\exp(-j2\pi ux_2) + \ldots \sqrt{g_n}\exp(-j2\pi ux_n)}{|P(u)| \exp(j\phi(u))}$$

$$= \frac{\exp(-j\phi(u))}{|P(u)|} \cdot [\sqrt{g_1}\exp(-j2\pi u x_1)+\sqrt{g_2}\exp(-j2\pi u x_2)+ \ldots]$$

In general $|P(u)| = 0$ will occur for some values of u, resulting in singularities in the above expression for F(u). This problem is usually eliminated by imposing a magnitude constraint on F(u), such that

$$F(u)=\begin{cases} \dfrac{\alpha\exp(-j\phi(u))}{|P(u)|} \cdot [\sqrt{g_1}\exp(-j2\pi u x_1) + \sqrt{g_2}\exp(-j2\pi u x_2)+\ldots] & \text{for } |P(u)|\geq\alpha \\ \exp(-j\phi(u)) \cdot [\sqrt{g_1}\exp(-j2\pi u x_1) + \sqrt{g_2}\exp(-j2\pi u x_2)+\ldots] & \text{otherwise} \end{cases}$$

where α is a constant that ensures that $|F(u)|$ is normalized.
This complex-valued filter function, F, will be implemented on the available spatial light modulator using the methods described in the article "Optimal realizable filters and the minimum Euclidean distance principle," Richard D. Juday, Applied Optics, Vol. 32 pages 5100-5111 (1993), or by other such methods.

One knowledgeable in the art can easily extend this to two dimensions. The unique filter generator outputs the values of the filter F to card storage device 22 on line 46. The card storage device stores filter F on a storage medium (such as a magnetic strip or smart card chip) of a card 20. Once this operation is accomplished, enrolment is complete and the individual leaves with card 20.

A subscriber may communicate his public key or decrypt a message utilizing apparatus 70 of figure 2. Further, another may encrypt a message with apparatus 70.

Turning to figure 2, apparatus 70 comprises an input system 129 with a laser 130, expander lens 131, collimator lens 133, and prism 135 which may be similar to the input system 29 of figure 1. A correlator 142 is in the information beam path 139. The correlator comprises a Fourier transforming lens 143, an electronically addressable (programmable) spatial light modulator (SLM) 144 in the back focal plane of lens 143, and

an inverse Fourier transform lens 146. The output beam 147 from the correlator inputs optical detector 148. Detector 148 inputs processor 80 on line 149. The processor also receives an input from card reader 72 on line 78. The processor outputs to the SLM 144 on line 79, to a pseudo-random number generator 84, and to a public/private key generator 88 on line 82. The pseudo-random number generator outputs to the public/private key generator which, in turn, outputs to a public key communicator 94 and, on line 92, to a decryption/encryption system 96. The public/private key generator also receives an input from public key receiver 95 and from keypad 74. The decryption/encryption system receives an input from an input message store 98 and outputs to an output message store 100.

A subscriber who wishes to transmit his public key places the same finger or fingers on the input screen 128 as were placed on the screen 28 (figure 1) during enrolment, his card 20 in reader 72, and presses button 76 of keypad 74. This activates light source 130 and the resulting output beam 139 from the prism is an information beam carrying the fingerprint pattern p′. The beam 139 carrying the spatial fingerprint information proceeds into the correlator 142 and passes through the Fourier transform lens 143. The filter information, F, stored on card 20 is read by reader 72 and input to processor 80. The processor converts the incoming digital filter information signals to analog SLM drive voltages. These drive voltages, which represent the filter information, are transferred into the SLM 144 on line 79. The filter written on the SLM 144 modulates the fingerprint's optical transform through a multiplicative method which is part of the optical correlation operation which compares the subscribers fingerprint(s) with those represented by the encoded filter F stored on the subscriber's card. The output from the SLM 144 is an optical signal S′ whose similarity to the transform function S depends on the degree of correlation between the input fingerprint(s) p′ and the reference fingerprint(s) p used to construct the filter F. If p and p′ are the same fingerprint(s) then S′ equals S. The optical signal 145 which comprises S′ passes through the second transform lens 146 and onto the optical detector 148 where its intensity distribution s′ is detected. When p′ equals p then s′ will be an intensity distribution representing g, the array of numbers which represent the unique number u. The output of the optical detector 148 inputs the processor 80 which calculates the unique number u from the array of numbers $\{g_1, \ldots, g_n\}$. If the error in detection by detector 148 only allows β distinct values between 0 and m-1 inclusive, where m is the dynamic range of the optical detector 148, we calculate:

$g_i^* = g_i(\text{measured}) \cdot \frac{\beta}{m}$ and round to integers

where $0 \leq g_i^* < \beta$.

Then $u = g_1^*\beta^{n-1} + g_2^*\beta^{n-2} + \ldots + g_n^*\beta^{\circ}$

The number u then acts as the seed number which inputs pseudo-random number generator 84. It is important to note that the pseudo-random number generator will generate the same random numbers whenever it is input with the same seed, in this case u. The random numbers derived by pseudo-random number generator 84 as well as u itself, on line 82, input the key generator 88. The key generator utilizes known public-key cryptographic techniques to derive a private key or a public key from these inputs. With button 76 of keypad 74 depressed, the key generator is prompted to output the public key on line 90 to public key communicator 94. Communicator 94 may simply be a display or it could be a transmitter such as a modem which transmits the number to a sendee.

If a subscriber has an encrypted message he wants to decipher, he may utilize apparatus 70 to decrypt same, as follows. The encrypted message is input to input message store 98. Then the subscriber (receiver) inserts his card 20 in card reader 72, depresses button 79 of keypad 74, and places his finger(s) on input screen 128. As before, the processor 80 generates the unique number u from the intensity distribution s' and this, along with the random numbers generated by random number generator 84 in response to the seed number u, input the key generator 88. In response to the prompt from button 79, the key generator utilizes these inputs to derive the private key. The private key then inputs decryption/encryption system 96 on line 92; the encrypted message stored in the input message store 98 also inputs system 96. The system 96 utilizes known public key cryptographic techniques to decrypt the message from these inputs. The decrypted message is then output to output message store 100 where it may be accessed by the subscriber.

If the person using apparatus 70 was not the person whose fingerprints were represented by the encoded filter F, then the optical signal S' derived from the multiplication of the filter F from the card with the Fourier transform P' of that persons fingerprint(s) will

not equal S. This will mean that the unique number u' indirectly derived from S' will not be equivalent to u. Consequently the key generated by the private/public key generator 88 will not decrypt the encrypted message.

An individual may send a subscriber an encrypted message utilizing apparatus 70 in the following manner. The individual stores a plain text message in input message store 98, depresses button 77 of operator input 74 and inputs the public key of the subscriber to public key receiver 95. This prompts the key generator 88 to directly input the public key from public key receiver 95 to the decryption/encryption system 96. The system 96 uses this key in encrypting the plain text message and outputs the encrypted message to output message store 100. The individual may then transmit the encrypted message to the subscriber in any non-secure manner. (It may be noted that the fingerprint and card reading subsystems of apparatus 70 are inactive when button 77 is pressed.)

It will be apparent that the system of this invention allows the use of public key encryption techniques without a subscriber knowing his private key. This enhances the security of the system. Yet further a lost card could not be used by a third party in apparatus 70 because the unique number u is only recoverable by inputting the subscriber's fingerprint.

Another advantage of the subject system is that the subscriber need not know his public key as it may be easily generated with the system of the invention. Furthermore, if an unauthorized individual broke in to an apparatus 70 of figure 2, he would have no way of determining the manner for generation of u since this number is only generated in the enrolment devices of figure 1 and is unique to each individual.

The robustness of the system of the present invention may be enhanced as follows. In the enrolment apparatus 10 of figure 1, the absolute value of one point of $g = \{g_1, \ldots. g_n\}$, for example g_1, may be stored on card 20. If this is done, then the processor circuit 80 of figure 2 may compare the intensity of this same point in the g function generated by optical correlator 142 with that point stored on the card and scale the elements of g from correlator 142 accordingly. This will reduce the effect of the "noise" present in apparatus 70. For example, dirt or oil on the input screen 128 could reduce the absolute

intensity of g. However, the relative intensities of the delta functions would be preserved. The absolute value could then be recovered by comparing one point of g generated by correlator 142 with that same point of g which is stored in absolute form on card 20.

In another embodiment of the invention, the unique number, u, is related to the location of peaks in the correlator output, rather than their relative intensities as considered so far. In this embodiment the filter F is designed to produce a series of equal-intensity peaks at the correlation plane detector. The peak locations are carefully controlled so that they occur within a grid of p by q cells on the detector. When n such series of peaks are displayed sequentially, the unique number u can be reproduced, using only the peak location information.

In this embodiment an individual will be enroled using the following procedure. With reference to figure 1, the individual will place their finger(s) on the input screen 28. As before, the fingerprint information is input to the ICDD 41. The digital output 42 of the ICDD is input to the unique filter generator 43 and to the unique number generator 44. The unique number generator 44 will assign the subscriber a unique number u as previously described. Then, the unique number generator 44 determines an array b which is related to the unique number u by the following relationship:

$$u = f(b,w)$$

where w is a constant for any specified number of peaks (t) and size of grid (p by q) as described hereinafter. For reasons which will also be apparent hereinafter, a convenient choice for the function is:

$$u = b_1 w^{n-1} + b_2 w^{n-2} + \ldots\ldots + b_{n-1} w^1 + b_n w^0$$

Thus, the coefficients b_1, b_2 ... b_n which determine the unique number u can be evaluated using modular arithmetic as follows:

$$b_1 = \text{Integer of } \frac{u}{w^{n-1}}$$

b_2 = Integer of $\dfrac{u \bmod w^{n-1}}{w^{n-2}}$

.

.

b_{n-1} =Integer of $\dfrac{u \bmod w^2}{w^1}$

b_n = Integer of $\dfrac{u \bmod w^1}{w^0}$

The unique number generator 44 then assigns each value of b_i to one of the possible permutations of arranging t peaks in a grid of p by q cells. One of the peaks is always located in the upper left cell of the grid, to serve as a reference peak. The number of permutations of locating the remaining t-1 peaks in the p.q-1 cells is given by w, where:

$$w = \frac{(p.q-1)!}{(t-1)!(p.q-t)!}$$

Thus, it is clear that each coefficient b_i has a value between 0 and w-1 inclusive. The assignment of the value of b_i to a particular pattern of peak locations is accomplished by using a randomised look-up table in the filter generator which relates every possible value of b_i (i.e. from 0 to w-1) to a unique permutation of peak locations in the grid. Thus, a two-way relationship between the value of b_i and the relative locations of peaks in the grid is established. Clearly then, if the subscriber can later reproduce the pattern of peaks in such a grid using the apparatus 70 of figure 2, then the unique number u can be regenerated and thus the subscriber can proceed. Note however, that because of the randomised look-up table, even if a pattern of peaks were discerned, it would bear no relationship to the corresponding value of the element of b unless the look-up were known.

The required locations of the peaks for each element, b_i, of b are input to the unique filter generator from the unique number generator. The unique filter generator calculates the filter, F_i, so that when the correct fingerprint (or fingerprints), p, is input to apparatus 70 of figure 2, the output function, s_i, is the specified arrangement of equal-

intensity peaks. This calculation uses the Fourier transform of the subscriber's fingerprint(s), P, and the same approach as described previously, with the exception that all of the delta-like functions are assigned the same peak height, and their relative locations are determined by b_i. (Therefore, in one dimension,

$$s_i = \delta(x-x_1)+\delta(x-x_2)+ \ldots\ldots + \delta(x-x_t)$$

where $x_1, x_2,\ldots\ldots, x_t$ are determined by the look-up table of peak locations for b_i.) Note that n such filters, $F_1, F_2,\ldots F_n$, corresponding to $b_1, b_2,\ldots b_n$, will be required to determine all the elements of b. The n filters are generated in this manner, and are then stored on the card 20. Thus, the enrolment process is completed and the user retains the card 20.

Where the subscriber to the system wishes to regenerate the unique number, u, to produce the private or public key, the following procedure is adopted. Turning to figure 2, when a subscriber places his finger(s) on the input 128 of apparatus 70, inserts his card 20 in the reader 72, and presses button 76 (to display his public key) or 79 (to decrypt a message), the processor causes the n filters from the card 20 to be transferred sequentially to the SLM 144 on line 79. A given filter, F_i, is multiplied in the correlator 142 with the Fourier transform, P, of the subscriber's fingerprint(s). The inverse Fourier transform of the result, which is the function s_i, is displayed on the correlation plane detector 148. With reference to figure 3, which schematically illustrates a portion of figure 2, the location of the first peak 150 in the detector 148 is determined by scanning across the detector from upper left to the bottom right. This first peak is considered to be the reference peak, and its position defines the grid 151 of p by q detection cells in the correlation plane detector, with the reference peak occupying the upper left cell in this grid. The detector output is then scanned over the area of the grid 151 and the locations of the other t-1 peaks are determined. Each of the t-1 peaks occupies a unique cell in the grid and the position of each is communicated to the processor 80 on line 149. The processor determines the element b_i of the vector b from the pattern of peaks by referring to the same randomised look-up table as used in the unique filter generator 43. The next filter, F_i, is then written to the SLM and thus the next element of b is determined and so on, until the entire array, b, is generated.

Since each element b_i, will have w possible values, b_i, is, in effect, a number in base w. It is for this reason that

$$u = f(b,w)$$

is chosen as

$$u = b_1w^{n-1} + b_2w^{n-2} + \ldots.. + b_{n-1}w^1 + b_nw^0,$$

because this equation converts the n elements of b from base w to base 10 which is more suitable for communication purposes. Thus, the unique number u is recreated using the apparatus 70 of figure 2, and can be input to the pseudo-random number generator.

In the example shown in figure 3, t=4 (there are 4 peaks), p=q=4 (a 4x4 detection grid is defined), and n=4 (4 filters are displayed sequentially). Thus, in this example, the unique number u would be capable of representing 455^4 or $4.3x10^{10}$ values.

This embodiment of the invention has the advantage of requiring only a binary search for correlation peaks, without regard to their intensity. It will thus be more resistant to any variations in the correlation peak heights caused by the correlator system noise.

A further embodiment of the invention would use the combination of peak height and location to generate the unique number, u, using the procedures described herein.

A subscriber may use his card created with the enrolment device of figure 1 to operate a PIN operated device, such as an ATM or a symmetric encryption/decryption system, utilizing apparatus 270 of figure 4. With regard to figure 1, the PIN may be derived from the unique number generator 44 or can be chosen by the system user 50.

Turning to figure 4 in which like parts to those appearing in figure 2 have been given like numbers, apparatus 270 comprises an input system 129 with a laser 130, expander lens 131, collimator lens 133, and prism 135. A correlator 142 is in the information beam path 139. The correlator comprises a Fourier transforming lens 143, an electronically addressable (programmable) spatial light modulator (SLM) 144 in the back

focal plane of lens 143, and an inverse Fourier transform lens 146. The output beam 147 from the correlator inputs optical detector 148. Detector 148 inputs processor 80 on line 149. The processor also receives an input from card reader 72 on line 78. The processor outputs to the SLM 144 on line 79 and to a PIN operated device 200 on line 282.

A subscriber who wishes to use the PIN operated device places the same finger or fingers on the input screen 128 as were placed on the screen 28 (figure 1) during enrolment and his card 20 in reader 72. This activates light source 130 and the resulting output beam 139 from the prism is an information beam carrying the fingerprint pattern p'. The beam 139 carrying the spatial fingerprint information proceeds into the correlator 142 and passes through the Fourier transform lens 143. The filter information, F, stored on card 20 is read by reader 72 and input to processor 80. The processor converts the incoming digital filter information signals to analog SLM drive voltages. These drive voltages, which represent the filter information, are transferred into the SLM 144 on line 79. The filter written on the SLM 144 modulates the fingerprint's optical transform through a multiplicative method which is part of the optical correlation operation which compares the subscribers fingerprint(s) with those represented by the encoded filter F stored on the subscriber's card. The output from the SLM 144 is an optical signal S' whose similarity to the transform function S depends on the degree of correlation between the input fingerprint(s) p' and the reference fingerprint(s) p used to construct the filter F. If p and p' are the same fingerprint(s) then S' equals S. The optical signal 145 which comprises S' passes through the second transform lens 146 and onto the optical detector 148 where its intensity distribution s' is detected. When p' equals p then s' will be an intensity distribution equal to g, the array of numbers which represent the unique number u. The output of the optical detector 148 inputs the processor 80 which calculates the unique number u from the array of numbers $\{g_1,.....g_n\}$. If the error in detection by detector 148 only allows β distinct values between 0 and m-1 inclusive, where m is the dynamic range of the optical detector 148, we calculate:

$g_i^* = g_i(\text{measured}) \cdot \frac{\beta}{m}$ and round to integers

where $0 \leq g_i^* < \beta$.

Then $u = g_1 * \beta^{n-1} + g_2 * \beta^{n-2} + \ldots .. + g_n * \beta^{\circ}$

The number u then acts as the PIN (private key) for operating the PIN operated device 200. Thus, the fingerprint of an authorised user will recover his PIN from his card without need for the user to know his PIN. On the other hand, because the PIN is secured by the fingerprint, the user may choose his/her own PIN for use with the PIN operated system.

The unique number u can also be generated using peak locations in the output of the correlator as described in a previous embodiment.

It will be apparent to those skilled in the art that input systems other than system 29 of figure 1 and 129 of figures 2 and 4 are available in order to produce a fingerprint information beam. Some of these other systems do not require a laser.

While it is preferred that the input to the input system is the fingerprint(s) of a user, the input system could be adapted to produce an optical signal impressed with characteristics from other body parts, such as a user's hand or iris. Indeed, any body part which has a unique signature comprises a biometric which may be suitable for use within the spirit of this invention.

While the systems of figures 2 and 4 have been described in conjunction with an optical correlator 142, it will be apparent to those skilled in the art that the correlator may be implemented digitally.

Other modifications will be apparent to those skilled in the art and, accordingly, the invention is defined in the claims.

WHAT IS CLAIMED IS:

1. A biometric controlled key generation system, comprising:
- a body part input for generating an optical information signal impressed with a biometric from a body part;
- Fourier transform means along a path of said optical information signal to obtain a Fourier transform representation of said information signal;
- a programmable filter responsive to said Fourier transform means for filtering said Fourier transform representation of said information signal to obtain a filtered Fourier transform representation;
- means for reading data from a data carrier storing filter information and for programming said programmable filter with said filter information data;
- inverse transform means responsive to said filter to inverse Fourier transform said filtered Fourier transform representation to obtain an inverse transform representation;
- key generating means responsive to said inverse transform means for generating a private key.

2. The key generation system of claim 1 wherein said key generating means comprises means to generate a seed number from said inverse transform representation, a pseudo-random number generator responsive to said seed number generator, and a key generator responsive to said pseudo-random number generator and said seed number generator.

3. The key generation system of claim 2 including means for storing filter information on said data carrier, comprising:
- a further body part input for generating a further optical information signal impressed with a biometric from said body part;
- image based seed number generation means to generate said seed number based on said further optical information signal;
- means to generate an array based on said seed number;
- means for obtaining a Fourier transform of said further optical information signal;
- means for generating filter information based on said Fourier transform of said further optical information signal and said array; and
- means for storing said filter information on said data carrier.

4. The key generation system of claim 3 wherein said body part input comprises a fingerprint input for receiving at least one finger of a user.

5. The key generation system of claim 4 wherein said data reading means comprises a card reader.

6. The key generation system of claim 5 wherein said Fourier transform means comprises a Fourier transform lens, said programmable filter comprises a programmable spatial light modulator, and said inverse transform means comprises a lens.

7. The key generation system of claim 3 wherein said data reading means is also for reading data from a data carrier storing an indication of an intensity of a component of an inverse Fourier transform and wherein said seed number generator is responsive to said data reading means to generate a seed number from said intensity indication as well as from said inverse transform.

8. The key generation system of claim 1 wherein said programmable filter is a spatial light modulator.

9. The key generation system of claim 2 including means for storing filter information on said data carrier, comprising:
- a second body part input for generating a second optical information signal along a path impressed with characteristics of a second body part;
- means to detect said second optical information signal;
- means responsive to said detection means to generate a second seed number and an array based on said second seed number;
- means responsive to said detection means and said second seed number and array generation means for generating filter information; and
- means for storing said filter information on said data carrier,
whereby said seed number and said second seed number are identical when said body part and said second body part are identical.

10. The key generation system of claim 1 comprising:

- a sensor to sense said filtered Fourier transform representation, and wherein:
- said data reading means is a card reader;
- said key generating means comprises a pseudo-random number generator, a private key generator connected to an oputput from said pseudo-random number generator, and a seed generator, said seed generator connected to (i) an output from said card reader (ii) an output from said sensor, (iii) an input to said pseudo-random number generator, and (iv) an input to said private key generator.

11. The key generation system of claim 1, adapted for use as a public key cryptographic system, comprising user controlled selection means and wherein said key generating means is responsive to said selection means for selectively generating one of said private key for decrypting a message and a public key for encrypting a message.

12. The key generation system of claim 11 including a public key decryption system for storing an encrypted message and, responsive to any private key generated by said key generating means, for attempting to decrypt said encrypted message with said private key.

13. The key generation system of claim 12 including public key input means for direct input of a public key to a public key encryption system, said public key encryption system for storing a plain text message and, responsive to any public key input to said public key input means, for encrypting said plain text message with said public key.

14. A method for generating a private key, comprising the steps of:
- generating an optical information signal impressed with a biometric;
- obtaining a Fourier transform representation of said information signal;
- receiving a filter and filtering said Fourier transform representation of said information signal with said filter to obtain a filtered Fourier transform representation;
- obtaining an inverse Fourier transform representation of said filtered Fourier transform representation;
- generating a private key from said inverse transform representation.

15. The method of claim 14 including the step of utilising said private key for decrypting a public key encrypted message.

16. The method of claim 14 wherein the step of generating a private key from said inverse transform representation comprises the steps of:

- generating a seed number from said inverse transform representation;
- generating a psuedo-random number responsive to said seed number; and
- generating a private key responsive to said seed number and said psuedo-random number.

17. The method of claim 16 wherein the step of receiving a filter comprises receiving a filter constructed from the steps of:

- generating a further optical information signal impressed with said biometric;
- generating said seed number based on said further optical information signal;
- generating an array based on said seed number;
- obtaining a Fourier transform of said further optical information signal; and
- generating a filter based on said Fourier transform of said further optical information signal and said array.

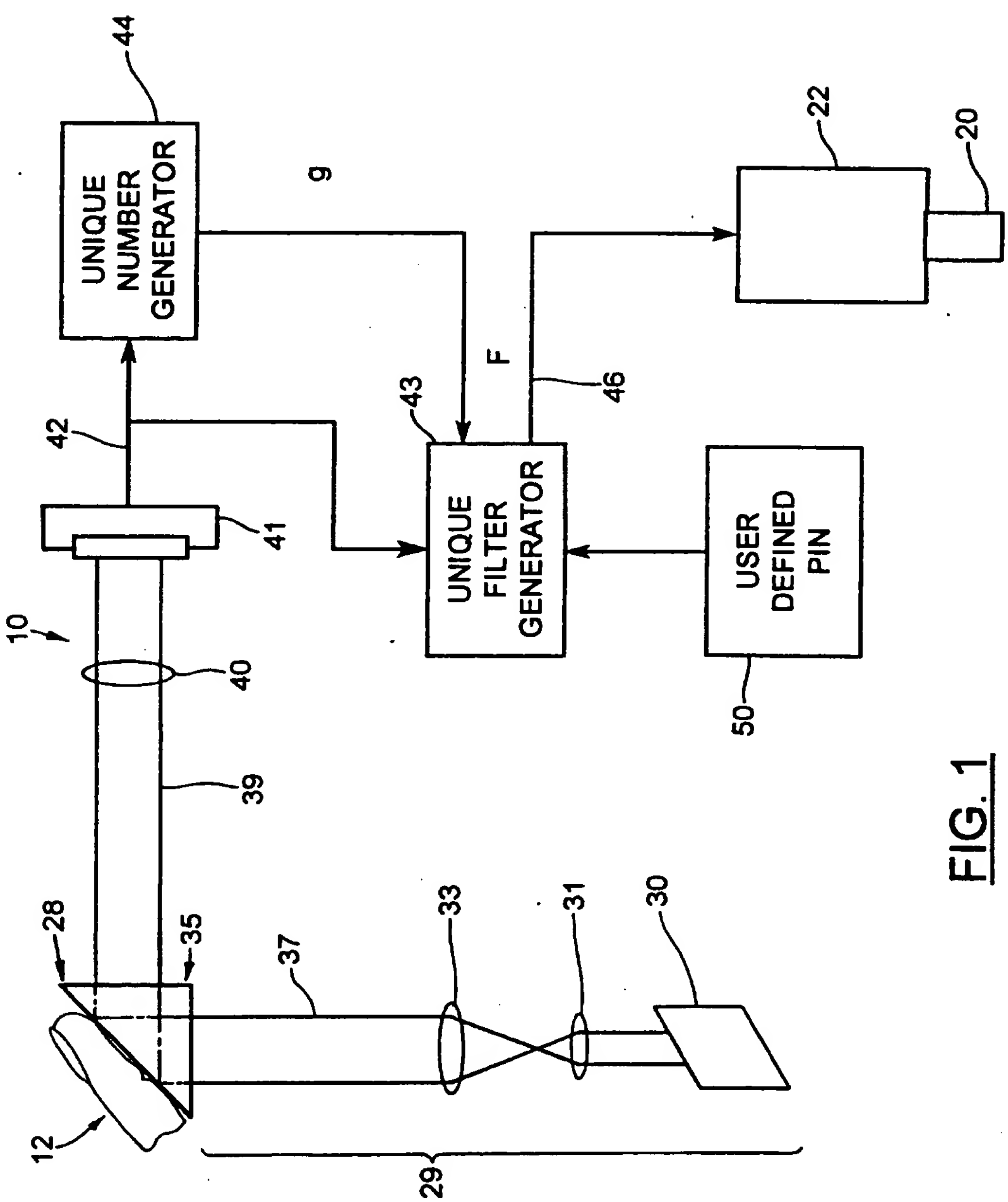

UNIQUE NUMBER GENERATOR
UNIQUE FILTER GENERATOR
USER DEFINED PIN
g
F
44
22
20
42
43
46
41
10
40
50
39
28
35
37
33
31
30
12
29

FIG. 1

2/4

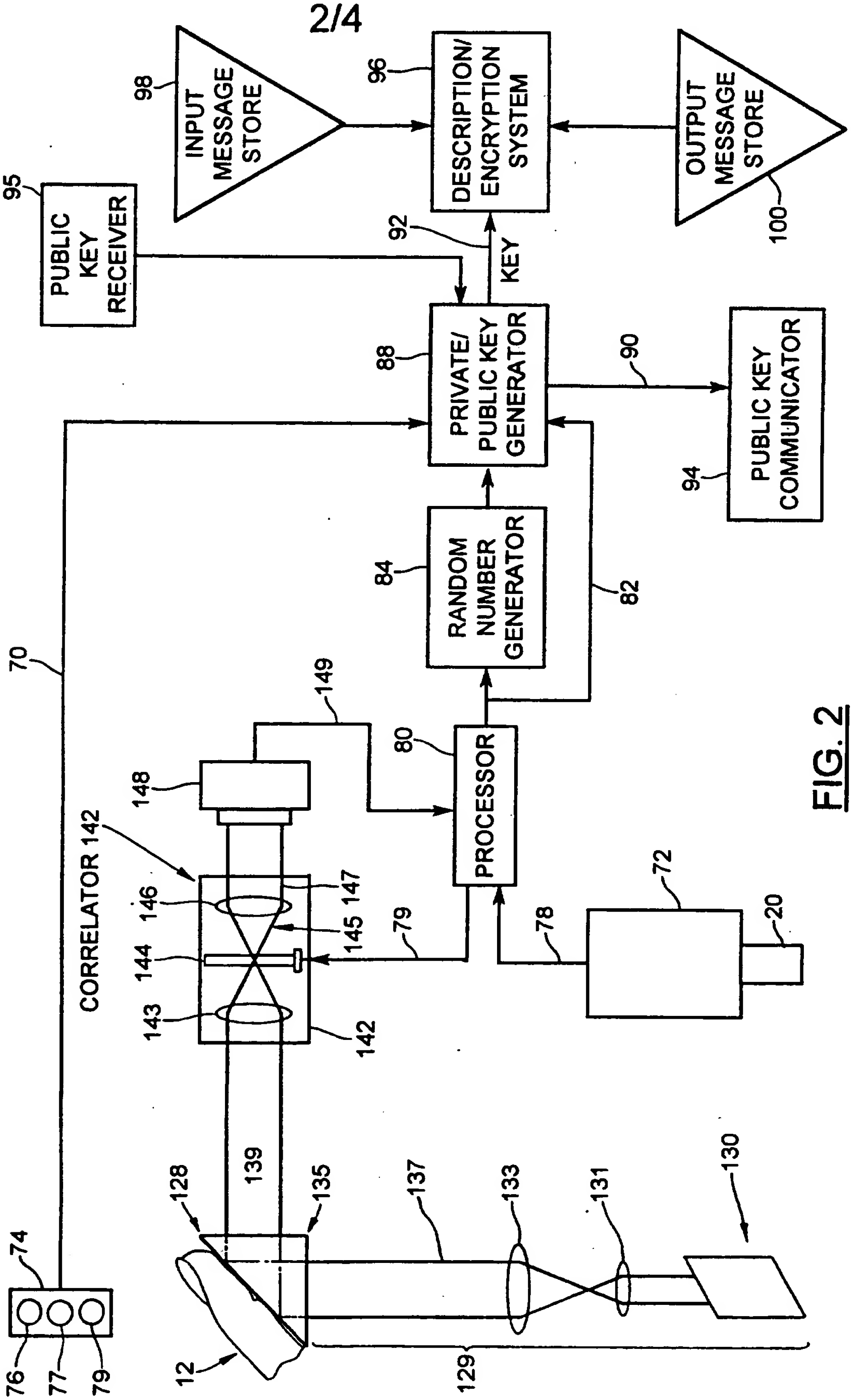

98
INPUT MESSAGE STORE
96
DESCRIPTION/ ENCRYPTION SYSTEM
OUTPUT MESSAGE STORE
100
95
PUBLIC KEY RECEIVER
92
KEY
88
PRIVATE/ PUBLIC KEY GENERATOR
90
PUBLIC KEY COMMUNICATOR
94
84
RANDOM NUMBER GENERATOR
82
70
149
80
PROCESSOR
148
CORRELATOR 142
146
147
145
144
79
78
72
20
143
142
139
128
135
137
133
131
130
74
76
77
79
12
129

FIG. 2

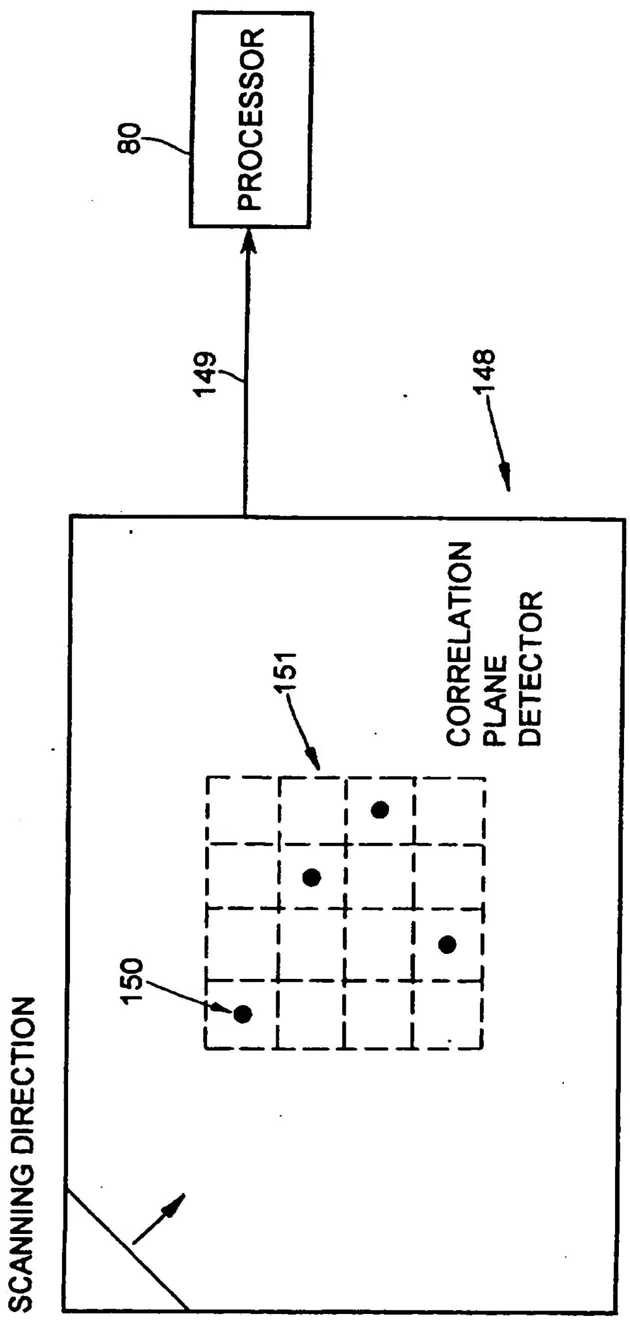
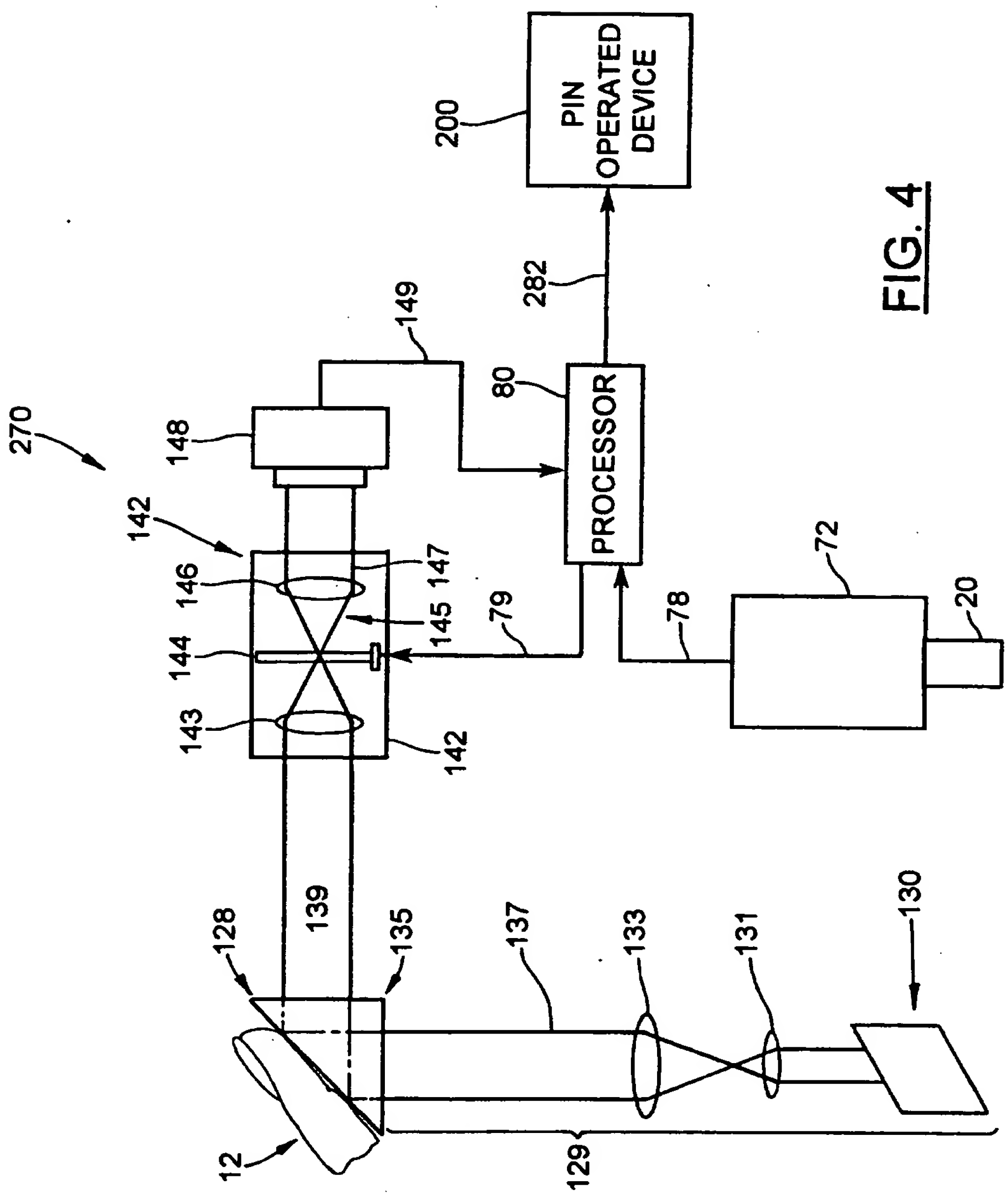

PROCESSOR
80
149
148
CORRELATION
PLANE
DETECTOR
151
150
SCANNING DIRECTION

FIG. 3



PIN
OPERATED
DEVICE
PROCESSOR
200
282
149
80
270
148
142
146
147
145
144
143
142
79
78
72
20
128
139
135
137
133
131
130
12
129

FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 95/00509

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L9/08 G07C9/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04L G07C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US,A,5 095 194 (BARBANELL) 10 March 1992 see column 3, line 43 - column 5, line 24 see column 6, line 28 - line 59 see column 7, line 35 - column 8, line 47 ---	1,14 4,5
Y A	DE,A,42 43 908 (GAO GESELLSCHAFT FÜR AUTOMATION UND ORGANISATION) 30 June 1994 see column 2, line 32 - line 48 see column 3, line 30 - line 51 see column 4, line 18 - column 5, line 17 ---	1,14 11
A	US,A,5 345 508 (LYNN ET AL.) 6 September 1994 see column 1, line 6 - line 12; figure 2 see column 5, line 25 - line 39; figure 2 --- -/--	2,10,16

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 November 1995	- 4. 01. 96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Holper, G

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US,A,4 876 725 (TOMKO) 24 October 1989 see column 3, line 40 - column 4, line 34 see column 5, line 60 - column 6, line 55 -----	1,3-7,14

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/CA 95/00509

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
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DE-A-4243908	30-06-94	NONE		
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		US-A-	5444781	22-08-95
US-A-5050220	17-09-91	NONE		
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		EP-A-	0411221	06-02-91